THE MAGAZINE OF THE WORLD HEALTH ORGANIZATION

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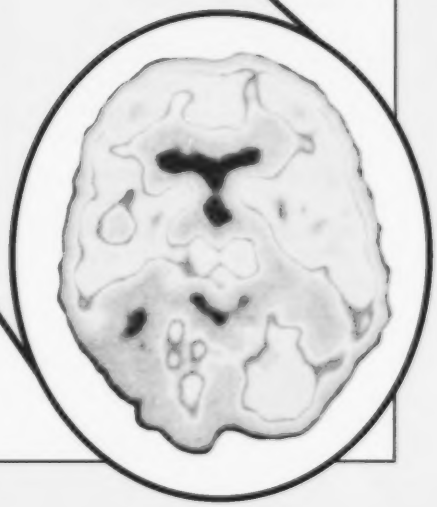
100 years of radiological science



X-rays 1895-1995

Radioactivity 1896-1996

THE MAGAZINE OF THE WORLD HEALTH ORGANIZATION

In this issue

Editorial

Radiation medicine for all 3
Maurice Tubiana & Gerald P. Hanson

Radiology: a century of progress 4
Otha W. Linton & Joseph Marasco

The discovery of radioactivity 5
Maurice Tubiana

WHO and radiation medicine 6
Gerald P. Hanson & Vladimir Volodin

Medical imaging in modern medicine 8
Lenny K.A. Tan

Profiles:
Radiologists – the doctor's doctor 10
Radiographers today 10
The medical physicist 11

The basics of diagnostic imaging 12
Philip E.S. Palmer & Thure Holm

Mammography: a woman's perspective 14
Cari Borrás

High tech at low cost 15
Peter E. Peters & Horst Lenzen

Ultrasound imaging in developing countries 16
Hassen A. Gharbi & M.W. Wachira

Nuclear medicine 18
Yasuhito Sasaki & Kiyoko Kusakabe

Radiotheraphy: still young after almost a hundred years 20
Jean-Claude Horiot & Suzanne Naudy

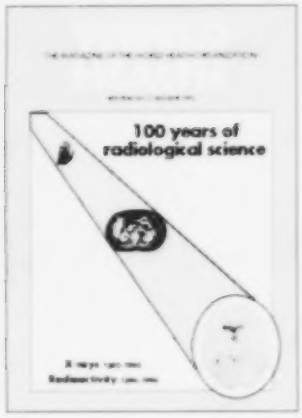
Quality assurance in radiotherapy 22
Hans Svensson & Björn Zackrisson

Protection against radiation in medicine 24
César F. Arias & Jorge J. Sikvarca

Radiology in the *next* hundred years 26
Alexander R. Margulis

The ethics of new technology 28
Sneh Bhargava

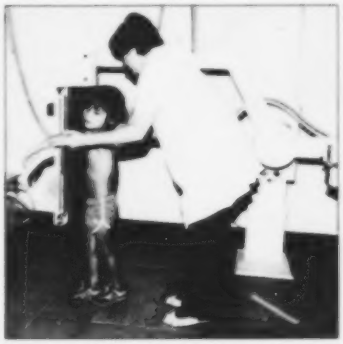
Multidisciplinary research for health 30
Boutros G. Mansourian & Bruce McA. Sayers



page 7

Our cover illustrates the advances made in radiological imaging over the last century. At the top, a radiograph taken by Röntgen in 1896 at the hand of his colleague, Professor von Kölliker. Centre, a computerized tomography (CT) image of the abdomen – a technique first used on patients in 1971. Bottom, modern nuclear imaging using Positron Emission Tomography (PET) records the cerebral metabolic rate of glucose in a patient with Alzheimer's disease.

page 16



page 22

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Editorial

Radiation medicine for all

Maurice Tubiana & Gerald P. Hanson

At the end of the 19th century all expectations for medical innovations were turned towards microbiology and biochemistry which were then in their infancy, and no one could foresee new advances from physics. Yet, in less than a decade after the discovery of X-rays by Röntgen, radiology added a new dimension to clinical examinations by making it possible to study hidden anatomical lesions in live patients.

Three dates stand out: in 1895, Röntgen discovered X-rays while experimenting with cathode rays (the same week that the Lumière brothers introduced cinematography in France). The reign of the image had begun. The following year, Becquerel in Paris discovered radioactivity and, in 1897, J.J. Thomson discovered the electron. Within a decade, Rutherford, Planck and Einstein laid the foundations of modern physics and its applications. In retrospect, one is filled with admiration for the creative genius of these scientists and the rapidity with which these discoveries were made and their applications were spread throughout the world.

This issue of ***World Health*** provides an overview of today's technology in radiation medicine, covering various aspects of diagnostic imaging, radiation therapy and radiation protection. Fundamental concepts of equity, quality and ethics are also explored, as well as WHO's policies and strategy.

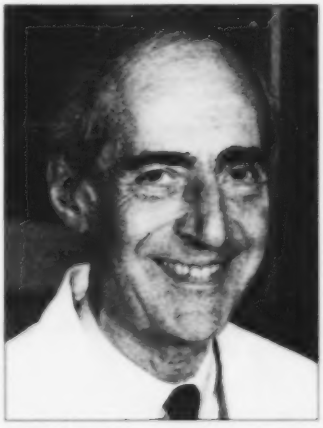
The issue of equity was clearly focused by radiologist Richard H. Chamberlain, in his seminal article "Basic radiology: a worldwide challenge", published in 1970, which pointed out that two-thirds of the world's population had no access to even the simplest X-ray procedures. When WHO adopted its strategy of Health for All, a remedy for this inequity – the Basic Radiological System (BRS), now updated by the WHO Imaging System-Radiography (WHIS-RAD) – was already being developed. Equity is also of paramount importance in radiation therapy; although over half of all cancer patients live in the developing world, the majority of the developing countries do not have radiation therapy services.

Efforts to improve equity must not result in useless or even harmful medical procedures. WHO has played a leading role in promoting the rational use of radiodiagnostic procedures, and has published recommendations on quality assurance, on radiation protection, and on the clinical indications for diagnostic imaging. The key elements for improving equity and quality are having sufficient resources and making rational and effective choices for their use, coupled with relevant education and training.

Medical imaging has achieved a technical level that was inconceivable 20 years ago, and this is only the beginning. The future for radiology is bright, with the promise of computer-assistance for obtaining, storing and transmitting images and for the planning of radiation therapy. Telematics opens a new door to teleprocessing of images and telemedicine. Tomorrow any physician, in any part of the world, will be able to seek on-line advice from the greatest specialists for the interpretation of a difficult image. Great hopes are now focused on molecular biology, biotechnology, computer science and physics, and the world eagerly awaits the fruits of multidisciplinary research.

By the year 2000, the world's population is expected to pass the 6000 million mark, and both WHO and its many collaborators fervently hope that vast segments of the population will have access to the most essential elements of radiation medicine. ■

> "***Science has no motherland, since human knowledge embraces the whole world.***" *Louis Pasteur*



Professor Maurice Tubiana, President Centre Antoine Béclère, Paris, and former President of the International Society of Radiology

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Radiology: a century of progress

Otha W. Linton & Joseph Marasco

Within weeks of the German physicist, Wilhelm Conrad Röntgen, discovering the X-ray and making an image of the bones of his wife's hand, in 1895, doctors all over adopted the new discovery as a giant step forward in medical care. For the first time, a doctor could see what was happening inside a patient. The location and extent of a bone fracture, a stone in the kidney or the presence of metal, as shown on an X-ray film, helped to guide the surgeon's knife. In a matter of months, other doctors were applying X-rays in efforts to cure a wide range of diseases including some cancers, arthritis, lupus and a variety of skin conditions which showed improvement after exposure to X-rays. During the same early years, workers in this field realized that their own repeated exposures caused inflammations and even cancers in their bodies.

Gradually, scientists and inventors like Thomas A.Edison improved X-ray equipment, making it more powerful, more accurate and safer to use. Using harmless liquids which are opaque to X-rays, doctors learned to identify in the pictures of body organs the changes that indicated disease. The growth of medical applications of X-rays and natural ionizing radiation impelled further advances in medicine. Early diagnosis of cancers, often by X-ray examinations, led to more successful treatments, again involving X-rays in massive amounts to destroy the cancer cells.

During the First World War, doctors for the armies on both sides relied on X-ray studies to diagnose battle fractures. In the process, many clinicians became reliant on the X-ray specialist – the radiologist – for diagnostic help with other problems such as pneumonias, skeletal malformations and some problems of the nervous system.

Refinements in equipment, opaque contrast materials, higher energy X-ray therapy sources, radium applicators for cancer and improved clinical techniques made steady progress up to and after the Second World War.

X-ray studies improved with the advent of photo-timing for sharper images and electronic image intensification of fluoroscopic motion studies. Special examinations such as mammography for the detection of breast cancers gained rapid acceptance.

In the early 1960s, ultrasound devices modified from wartime sonar and radar uses began to supplement X-rays and isotopes for the study of organ function. Since they did not involve ionizing radiation they were particularly attractive for studies of pregnant women to detect fetal abnormalities.

The computer age made a dramatic impact on radiology in the early 1970s. First, computerized tomography (for which G. N. Hounsfield was awarded the Nobel Prize in 1979) allowed cross-sectional studies, combining thousands of bits of information to form clear images which revealed new information to radiologists and physicians. A decade later, another cross-sectional imaging technique, magnetic resonance, used intensive artificial magnetic fields to generate radio signals from patients' bodies. Again, computers analysed the information to create a sophisticated image.

The centennial of Röntgen's 1895 discovery of X-rays finds radiological techniques firmly established as an essential part of medical diagnosis and treatment. Today, physicians who specialize in radiological procedures are supported in their clinical work by radiobiologists and physicists, dosimetrists, engineers, and computer scientists. ■

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The discovery of radioactivity

Maurice Tubiana

The image age began in [illegible] when Wilhelm Conrad Rontgen discovered X-rays while experimenting with cathode-ray tubes. Within weeks, radiological photos taken in Vienna, Paris and London were already enabling doctors to make diagnoses.

As he examined one of those pictures, in Paris in January 1896, Henri Becquerel became interested in the mechanism by which X-rays are produced and particularly in its links with fluorescence. Two months later he showed that a natural element, uranium, spontaneously emits rays closely resembling X-rays. It is from this discovery of natural radioactivity that emerged, first radium – isolated by Pierre and Marie Curie in 1898 – and then its medical applications, greater understanding of the structure of the atom, radiochemistry, artificial radioactive isotopes and – eventually – atomic energy. The discovery of the electron in 1897 by Joseph John Thomson laid the basis for modern electronics and specifically for its medical applications.

Thus, within the space of three years, three discoveries – of X-rays, radioactivity and electronics – were made which were to dominate the 20th century. In 1934, the discovery of artificial radioactivity by Irène and Frédéric Joliot-Curie gave a new boost to the medical applications of radioactivity. We learnt how to manufacture radioactive isotopes from most of the natural elements and, thanks to the radiation that they emit, we could track them or the molecules into which they had been introduced in the interior of the organism. This method of using trace elements had been pioneered by Georg von Hevesy with natural radioisotopes since 1913. Antoine Lacassagne discovered the principle of autoradiography in 1922. It was on these foundations that nuclear medicine was to be rapidly built up between 1935 and 1939, and especially after 1945.

early X-ray images

Using trace elements

From 1948 onwards, patients were being injected with artificial radioisotopes to see what became of them, thus permitting the study of their topographical spread within the body. For instance, by examining what happens to radioactive iodine introduced into the thyroid, we can measure the radioactivity of this gland and observe its morphology. Subsequently scintigraphy and the scintigraphic camera provided high quality images which can be analysed to assess the functions of different parts of a single organ. Since 1970, scintigraphy has become an essential tool for exploring the functioning of a great number of organs and associated tissues. Thanks to the positron camera, tomoscintigraphy and functional imaging, nuclear medicine is today one of the most dynamic branches of medical imaging.

The use of radioactive tracers has afforded biology a great leap forward because of its extraordinary sensitivity which enables us to track small numbers of atoms or molecules. It has been a decisive tool in the birth and development of molecular biology.

Alongside radiodiagnosis and nuclear medicine, radiotherapy forms the third branch of radiology. It was born in 1896, but the discovery of radium in 1903 gave it a new dimension. The progress made over the past hundred years has confirmed it as one of the principal weapons for treating cancer. In any effective cancer control programme today, radiotherapy – alone or in association with surgery or chemotherapy – is needed for over half of the patients suffering from cancer.

Radiobiology and radioprotection also deserve a mention. From the first years of this century, it was known that ionizing radiation can cause cancer and leukaemia. Between 1920 and 1939, the frequency of leukaemia among radiologists was ten times higher than among other physicians. In 1934, we first began to understand the relation between the dose and the risk of cancer; a number of simple rules of radiation protection were laid down and a maximum permissible dose limit was introduced. Although this was relatively high compared with the levels enforced today, those recommendations were sufficient to check the excess of leukaemia in radiologists; since 1950, that frequency is no higher among radiologists than among other doctors. ■

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WHO and radiation medicine

Gerald P. Hanson & Vladimir Volodin

uring the first decade of its existence, WHO initiated activities in radiation medicine and also responded to public apprehension about radiation hazards. Among WHO's early published reports were ***Effects of radiation on human heredity*** (1957), and ***Postgraduate training in the public health aspects of nuclear energy*** (1958). Scientific interest in radiation risk and laboratory procedures gradually took into account public health concern about the provision of essential radiological services for diagnosis and therapy. Today hardly a hospital of any size is built without having a diagnostic imaging service or a plan for one.

Services for all

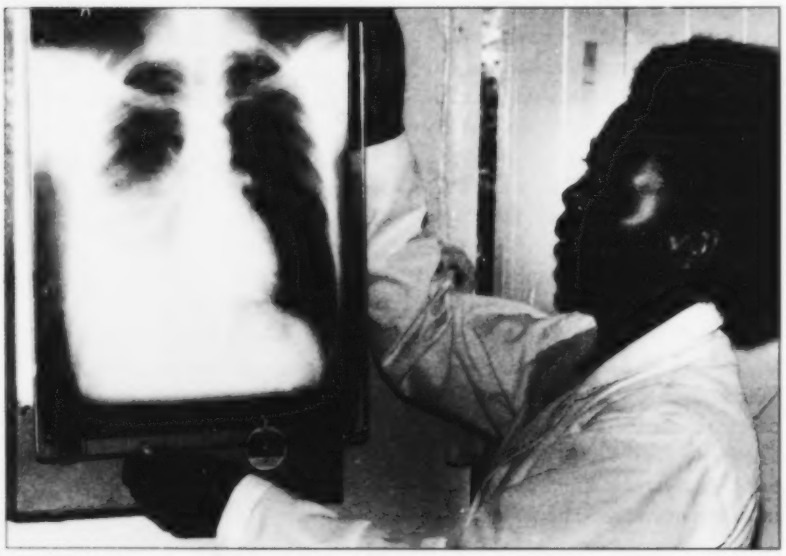
A substantial change in WHO's programme emphasis was the result of the International Conference on Primary Health Care, held in Alma-Ata in 1978. As the health status of a large portion of the world was unacceptable, the primary health care approach was imperative. In 1981, the World Health Assembly unanimously adopted a global strategy and Health for All became the overall goal of WHO.

Radiological services for diagnosis, therapy and prevention (protection against risks) are designed to serve all the population rather than concentrating on a specific group or disease. Logically, demographic and epidemiological considerations must guide the establishment of priorities. For example, as the proportion of elderly persons increases, the incidence of chronic and degenerative diseases and diseases related to industrialization and urbanization are expected to increase. Accidents, injuries and violence are becoming a serious cause of mortality and morbidity in developing countries and in some places now rank among the first five causes of death.

Based upon the epidemiological situation and the expected health care that will be needed for most of the population, the types of X-ray examination most likely to be needed by small rural and district hospitals throughout the developing world are those of the chest, skeleton (including the head), abdomen and soft tissue.

The fundamental objective of WHO's programme in radiation medicine is to increase access to diagnostic and therapeutic radiological services while maintaining their quality and safety. There are three major areas.

- ***Diagnostic imaging*** is involved in many crucial medical decisions, but only about one-third of the world's population has access to even the most essential services and the quality is often questionable.
- ***Radiation therapy*** is required for more than one-half of all cancer patients, yet the necessary technology for treatment, including accurate dose delivery, is often lacking.
- ***Radiation protection and safety*** are absolutely essential, because more than 95% of all man-made ionizing radiation exposures are caused by medical use.



A radiographer examines an X-ray obtained by using the Basic Radiological System in Kenya

Diagnostic imaging

Since some two-thirds of the world's population lack any diagnostic imaging services, WHO concentrated on developing the Basic Radiological System (WHO-BRS) during the period 1975–85, and recently prepared its updated version, the WHO Imaging System-Radiography (WHIS-RAD). Currently the WHO-specified equipment is produced by several leading manufacturers and about 1000 units are installed in some 60 countries. Efforts are also being made by WHO, in collaboration with the United Nations

Industrial Development Organization (UNIDO), to promote the manufacture of these X-ray machines in developing countries.

In recent years, ultrasound has merited high priority because of its value in small hospitals once there are properly trained staff. Attention is also being given to intermediate-level or general-purpose radiology for referral hospitals beyond the level of basic radiology. Guidance is provided on selecting appropriate equipment, training the staff, introducing quality assurance programmes, and ensuring radiological protection. When governments request it, WHO provides technical cooperation for specialized radiology services in large urban or university hospitals.

Quality assurance, radiation protection and the rational use of radiation – including methods for saving resources, improving quality, and reducing doses to patients – are key elements in the effort to make sure that equal access does not result in wasteful health care.

WHO has convened a number of scientific meetings and issued clear recommendations on the clinical indications for major diagnostic X-ray investigations, including when radiological investigations are not justified. This guidance can be found in ***Effective choices for diagnostic imaging in clinical practice***, published in 1990.

Radiation therapy

WHO's strategy for extending radiation therapy services concentrates on those cancers affecting large numbers of people, which are amenable to such treatment. Radiation therapy, alone or in conjunction with surgery or chemotherapy, is required for more than half of all cancer patients.

WHO and the International Atomic Energy Agency (IAEA) have initiated a number of activities for improving cancer care, directed toward the needs and requests of Member States. These include a global network of Secondary Standard Radiation Dosimetry Laboratories to improve the accuracy of radiation dosage, as well as training courses in radiotherapy in various parts of the world. The global network now includes 73 laboratories in 56 countries, 43 of which are developing countries.

The radiographer prepares a young boy for a chest X-ray in Colombia.

Radiation protection

WHO has also been concentrating on matters of radiation protection during its efforts to extend diagnostic and therapeutic coverage, thereby ensuring that the provision of these health benefits will not cause harm. It is crucial to incorporate radiation protection concepts in the planning of medical diagnostic and therapeutic services, and to promote the coordination of quality assurance and radiation protection procedures. WHO provides technical cooperation to countries for their national radiological protection services or to help establish such services.

WHO and several other international organizations collaborated in preparing the new ***Basic safety standards*** for radiation protection in industry, medicine and agriculture, and a revised edition of the ***Manual on radiation protection in hospitals and general practice***, covering all aspects of the use of ionizing radiation in medicine is now being prepared.

The future

Within almost any health care system, there is a spectrum of imaging needs and the associated equipment which ranges from the most essential, such as the WHO-BRS or WHIS-RAD, to the most complex, such as computerized tomography or magnetic resonance imaging. Issues to be resolved are the clinical decision-making process through which diagnostic imaging examinations are selected as well as the optimum mixture of diagnostic imaging modalities.

In parts of the world such as Africa and South-East Asia, where the major issue is the shortage of personnel and equipment, efforts should concentrate on training nationals in their own countries using the equipment available. Where radiological imaging and radiotherapy have been available for many years, as in Latin America, international cooperative efforts should be directed towards improving quality in the delivery of services. Likewise, the quality of radiation protection services will have to be improved in some countries and these services must be started from zero in others. ■

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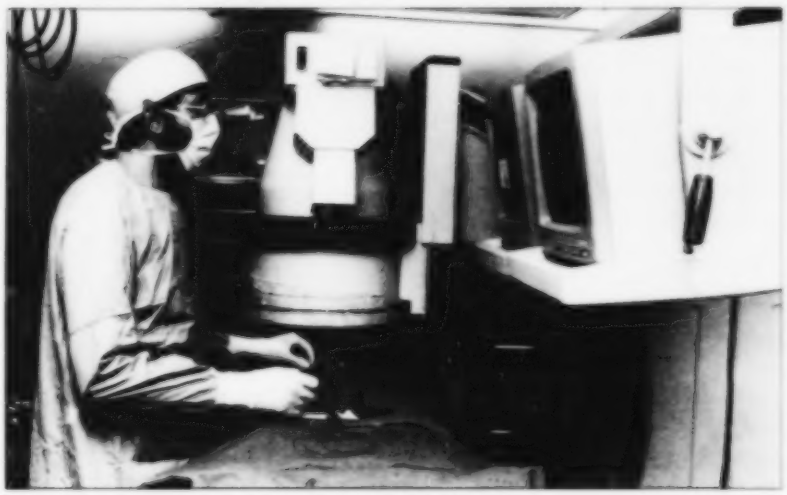
Medical imaging in modern medicine

Lenny K.A. Tan

The next hundred years will no doubt produce further technical advances in radiology. But it will still take the trained eye of the physician radiologist to apply this technology to each patient's health problems.



A surgical intervention carried out under X-ray control

Sooner or later, your doctor is going to look at his clinical notes and tell you "we need to make an X-ray examination to find out what is causing your problem". In recent years, the doctor has been using newer imaging techniques – "isotope study", "ultrasound", "computerized tomography" or "magnetic resonance image"; all these are part of the modern discipline of radiology, which marks its 100th year in 1995.

In many countries, medical imaging is as common, as simple and as safe as a doctor's use of a thermometer or stethoscope, and it extends a doctor's powers of observation beyond what he or she can see or touch or hear. The risk involved in a medically justified and properly conducted X-ray examination is usually so low that it is far outweighed by the expected medical benefit.

Such images depict the passage of X-rays through our bodies and their partial absorption by different body organs and structures. To an X-ray beam, our bodies have four densities. Bones are the densest and block the most X-rays, while the air space in our lungs lets most of them pass through. The water density of the intestines and the fat densities of the muscles fall somewhere in between. The radiologist or other physician must become proficient in recognizing an abnormal shadow indicative of disease conditions. Thus, many forms of cancer are denser on X-rays than the normal tissues surrounding them. If the radiologist is interested in movement, a device called a fluoroscope allows real-time viewing of the beating of the heart, the pulsing of blood through an artery in the head, or the flushing of urine from the kidneys.

If the radiologist wants to look at the inside of an organ system, the patient is given a liquid such as barium sulfate which is opaque to X-rays. The radiologist can watch it flow through the oesophagus, into the stomach and ultimately the intestines, revealing narrowings, blockages, ulcers or even cancers in the lining of the digestive system. Other opaque liquids can be injected into blood vessels to look for narrowing or blockages which contribute to strokes or heart attacks.

Radioactive scanning

Today's radiologist has other choices of imaging techniques besides X-ray studies. Many health problems can be detected and diagnosed by using trace amounts of radioactive substances, for instance an isotope called technetium 99m. The patient swallows or is injected with a tiny amount of technetium in a harmless chemical which concentrates in the organ to be studied. A sciatillation detector called a gamma camera records the pattern of radiation taken up by that organ. If a cancer is present in the liver, for example, the isotope scan pattern is abnormal because the cancer absorbs the isotope differently from normal tissue.

With computerized tomography, the radiologist uses a complex

machine involving multiple X-ray sources and absorption detectors. The resulting image is a cross-sectional view, a bloodless slice, through the body. By viewing a series of slices at close intervals, the radiologist can get a complete profile of a body organ. A still newer cross-sectional imaging technique, magnetic resonance (MR), uses multiple image detectors and a computer integration programme. Instead of X-rays, it relies upon a strong magnetic field to generate radio signals from the atoms of our bodies. As with X-ray studies, contrast liquids can be given to the patient to enhance visual distinctions in complex body structures.

For ultrasound examinations, a pulsed beam of sound above the audible range is directed into a patient's body. Various body structures reflect the sound beam differently. These reflections make a pattern on a screen showing yet another version of anatomy and motion. After more than 30 years of use, no adverse health effects have been detected, making ultrasound ideal for examining the status of unborn babies or in other circumstances where a patient's exposure to large amounts of X-rays might be hazardous.

Special skills needed

For most X-ray, ultrasound, and nuclear medicine examinations, a technologist works with the patient to obtain still images for study by a radiologist. The radiologist usually participates in motion studies. But a radiologist or another specially trained physician is always involved in interventional radiology – procedures in which fluoroscopic studies are made of the motion of blood vessels or other body channels. In most medical systems, a patient's own doctor decides if an imaging procedure is needed and refers the patient to a radiologist. The referral may be to a hospital X-ray department, a private office or a clinic. Sometimes, the patient's physician may have his or her own X-ray equipment and perform the examination.

There are a few circumstances where an encounter with a radiology procedure does not depend on a doctor's referral. These are usually for population screening. The most commonplace example is the use of chest X-rays to detect tuberculosis in people who have no symptoms. In some countries, women over the age of 40 are urged to get regular breast X-ray examinations – mammograms – for the detection of breast cancer.

A hundred years of X-ray science have made medical imaging a vital part of modern medicine. The next hundred years will no doubt produce still further technical advances in radiology. But it will still take the trained eye and educated mind of the physician radiologist to apply this technology to each patient's health problems. ■

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Use of radiation in medicine: some historical notes

Röntgen's discovery of X-rays occurred in November 1895, and the results of his pioneering work were reported to the Society for Physical Medicine of Würzburg the following month. What is perhaps less well known is that, as early as 18 January 1896, a distinguished Hungarian physician, Endre Hogyes, published a paper in a Hungarian medical journal, *OrvosiHetilap*, in which he suggested that the new technology might have potential applications in medicine. His paper, entitled "Photography of the skeleton through the body using Röntgen's method", is illustrated by a series of remarkable radiographs, including one showing the skeleton of a frog (see alongside). This photograph seems never to have been reproduced after the original 1896 publication.

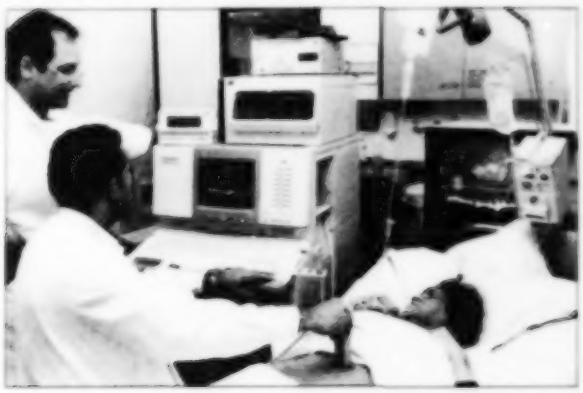
The first radiological journal, the *Archives of Clinical Skiagraphy*, was launched in London in April 1896, while in the following year the X-ray Society (later renamed the Röntgen Society) was established, also in London.

Finally, the era of radiation protection legislation appears to have begun in October 1899, when the Provincial Government of Lower Austria issued a Decree (No. 8831 of 21 October 1899) imposing stringent conditions governing the use of X-rays for diagnostic or therapeutic purposes – a harbinger of the massive, and complex, regulatory standards that were to follow much later in many other countries.

Contributed by Sev S. Fluss, Adviser on Health Legislation to Director, Division of Publishing, Language and Library Services, WHO, Geneva, Switzerland.

PROFILES • PROFILES • PROFILES • PRO

Radiologists – the doctors' doctors



Radiologists studying an echogram

No, radiologists don't repair radios! Since Röntgen discovered the X-ray 100 years ago, the term "radiology" has been used to denote the medical uses of radiation and "radiologist" to designate the medical doctor who specializes in radiological sciences.

First and foremost, radiologists are physicians of more than one kind. Diagnostic radiologists diagnose everything from fractures and tuberculosis to brain tumours and complications of pregnancy. Therapeutic radiologists use radiation to treat – and often cure – diseases. And nuclear medicine denotes the medical uses of special radioactive isotopes in both the diagnosis and treatment of diseases.

Radiologists are also consultants and have occasionally been described as "the doctor's doctor". As rapid advances in medical imaging have provided radiologists with unparalleled capabilities to examine the human body without the discomfort and risk associated with surgical exploration, other physicians have increasingly turned to them for assistance in diagnosis.

Accurate, highly detailed pictures of the body from top to bottom can now be obtained quickly and non-invasively. In fact, radiology is itself an outmoded term since many new medical imaging techniques don't use X-rays at all. Various forms of electromagnetic energy can be employed to diagnose and treat a broad spectrum of diseases. For example, ultrasound studies use sound waves to peer inside the body. A relatively new technique, magnetic resonance imaging (MRI), uses special radiofrequency pulses. MRI can provide dynamic images of the beating heart as well as exquisitely detailed studies of such tiny structures as the inner ear.

Although buying and maintaining equipment is expensive, as is the training of technologists and radiologists in large areas of the world, medical imaging research is providing increasingly accurate ways of diagnosing and treating many of the diseases that afflict mankind. Physicians everywhere are discovering that the radiological sciences – and their practitioners, the radiologists – are their staunch allies in the quest for better health. ■

Contributed by Professor Anne G. Osborn, University of Utah Medical Center, 50 North Medical Drive, Salt Lake City, UT 84132, USA. She is Chairman of the International Commission on Radiological Education.

Radiographers today

Students taking notes at the Radiological Technologists' Education Centre in Japan

The job of the radiographer has changed dramatically in the past few decades. The early technicians who made photographic records (radiographs) of anatomical structures have now, in the industrialized world, become "radiological technologists" (RTs) involved in complex functional studies using computer images.

Radiological technologists also work in radiotherapy – treatment by the application of radiation from outside the body or using radioisotopes – and also hyperthermia using non-ionizing radiation (microwaves or ultrasound). While radiation and radioisotopes are extremely beneficial tools for medicine, they can be very harmful if misused. RTs consequently have to learn to pay careful attention to the protection of the patient and safety control.

Over the years the RT has evolved into an independent profession, part of a closely integrated team of medical specialists, physicists, nurses and others. Three-year courses are now available in many countries, providing a solid basis for developing skills and offering vital hospital experience as a compulsory part of training. Young people today wishing to apply should have a good preparation in basic science and a sensitivity to the needs of their fellow human beings. A genuine wish to be of

service is a prerequisite and good communication skills lead to opportunities in teaching and management as well as research.

The Japan Association of Radiological Technologists Education Centre (JARTEC), a WHO Collaborating Centre for the Training of Medical Radiological Technologists, is operated by the Japan Association of Radiological Technologists, and accepts students from overseas for training each year. It also financially assists radiological technologists in other countries to acquire new technology, and promotes academic and technological research and development as well as continuing education.

International understanding of the rapid changes in this profession is helped by the experience of individual national societies. They help each other by producing journals and organizing conferences, often in association with the International Society of Radiographers and Radiological Technologists (ISRRT) which is a non-governmental organization in official relations with WHO. ■

Contributed by Dr Mitsuo Nakamura, Director of the Japan Association of Radiological Technologists Education Centre (JARTEC) and the WHO Collaborating Centre for the Training of Medical Radiological Technologists, 1301 Kamiyoka, Sukagawa City, Fukushima 962-02 Japan, and Miss Marion Frank, Radiographer, 16 Hallam Court, 63 Lancaster Gate, London W2 3NJ, England. Dr Nakamura is also President of the International Society of Radiographers and Radiological Technologists.

The medical physicist

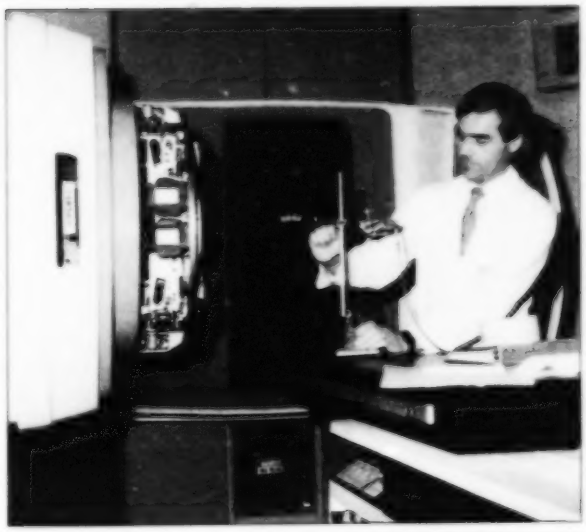
The human body can be regarded as a machine controlled by the world's most sophisticated microcomputer, the brain, which is about the size of a grapefruit and largely self-programmable. The machine is largely waterproof and entirely rustproof, self-propelling in any direction and equipped with a pair of sensitive manipulators. Control is effected, with automatic feedback, through self-adjusting binoculars and by auditory, olfactory and tactile signals. The machine is powered by a wide variety of fuels via a single multipurpose carburettor system. It can self-replicate at minimal cost and, although no guarantee is provided, has an expected lifetime of about 70 years. To some extent, it is even self-repairing.

To view the inside of the machine without causing pain, medical physicists, with colleagues in radiology and nuclear medicine, have developed a variety of techniques to image the internal organs from practically any angle. These methods make use of X-rays (computerized tomography scanning), magnetic fields (magnetic resonance imaging), radioactively labelled pharmaceuticals (radionuclide imaging), minute electrical impulses (applied potential tomography), ultrasound (ultrasonic imaging) or lasers (laser doppler imaging), whichever is most appropriate. To examine the functioning of various parts through physiological measurements (often of tiny electrical signals), methods that are largely noninvasive have been developed by medical physics departments in collaboration with colleagues in such diverse fields as cardiology, audiology, ophthalmology, neurology and urology.

Medical physics departments have made major contributions over many years to treatment planning and dosimetry, and they have been concerned with the operation and maintenance of equipment, devising improved procedures, and ensuring protection against radiation. Other important areas of collaboration include the use of ultraviolet radiation for skin disorders, and lasers for surgery. For internal treatment, the mechanical engineering, electronic engineering and computing expertise of multidisciplinary medical physics teams has been exploited in developing artificial heart valves, limbs and organs. The same expertise has also produced ingenious, relatively low-cost, technical aids for handicapped people, tailored to individual needs for everyday living.

Medical physics departments provide a very cost-effective base for the cross-fertilization of expertise in science and technology, which is essential to meet the needs of patients and their doctors. ■

Contributed by Professor Keith Boddy, President of the International Organization for Medical Physics (IOMP), and Head of the Regional Medical Physics Department, Newcastle General Hospital, Newcastle upon Tyne NE4 6BE, England.



A medical physicist runs a test on a linear accelerator before putting it into clinical service.

The basics of diagnostic imaging

Philip E.S. Palmer & Thure Holm

A patient is brought to a radiological centre in Sweden.

For a little girl with a possible broken arm, the first problem is to reach the X-ray centre.

From first aid to primary care to first-referral hospital, doctors need to know more about their patients, not only judging from the outside but finding out what is going on inside as well. People visit doctors for very much the same reasons, whether they are in big cities, small towns or out in the country. Often they have been injured and accurate assessment to exclude a skeletal fracture presents a major clinical need for diagnostic imaging. Or they have some illness, in which case much can be learnt with a stethoscope, but a radiograph could tell more. The third major need for diagnostic imaging arises in pregnancy: if either the mother or the baby appears not to be progressing as expected, the doctor or midwife will want to see an ultrasound scan.

Thus the basic equipment of any imaging department is self-evident: a good general X-ray set and a general purpose ultrasound unit. For years after Röntgen's discovery, "diagnostic imaging" meant only "radiography", the use of X-rays to obtain a radiograph (an X-ray film), but in the last 50 years many other imaging methods have been developed. Of these, ultrasound is the most useful, most often used, and least harmful. Together with radiography, ultrasonography is now firmly established as a basic aid for diagnostic investigations.

Ultrasound cannot image fractures or other skeletal diseases, nor can it image the lungs. Therefore, unless most of the patients are pregnant, the most essential requirement is an X-ray unit. However, in its own way, ultrasound is equally important and not just for obstetrics. It is better at imaging the pelvic contents, the liver, pancreas, spleen and kidneys, the thyroid and the neonatal head. There is really no valid choice between the two. To provide good patient care, doctors need the help of both X-rays and ultrasound.

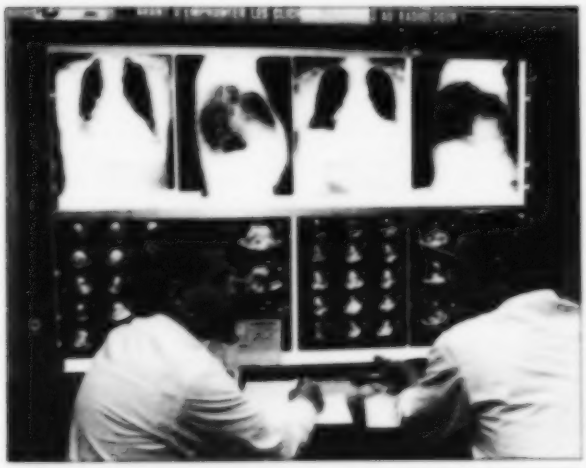
It is difficult to choose equipment because there are so many alternatives but WHO has, with the advice of a group of experts, laid down some basic criteria to simplify the choices.

Five principles must be followed:

- the quality of the images must be excellent;
- the equipment must be safe for both patients and personnel;
- the equipment must be easy to install and use;
- the equipment must be reliable and usable even when the electrical supply and other services are substandard;
- the equipment should need minimal maintenance care.

It is really not difficult to satisfy these basic requirements because today's imaging equipment can make use of advanced and sophisticated designs to produce something easy to use; after all, a pocket calculator is simple to use but it contains some very advanced electronic wizardry.

Most X-ray equipment has many technical parameters which can be altered when used with patients. This may reduce the image quality and increase the radiation dose to the patient and often to the staff as well. To counteract this risk, the WHO Imaging System – Radiography



Whether obtained by X-ray or by ultrasound, the images will help to make the correct diagnosis

analysis.

Specifications are also available for darkroom equipment, and manuals are published by WHO in many languages to explain radiographic technique, film processing in the darkroom, and X-ray film interpretation. The WHO *Manual of diagnostic ultrasound* has just been published this year.

(WHIS-RAD) requires that most of these variables are fixed at the optimum setting. This has not reduced the flexibility of the design, which can easily provide over 100 standard radiographic projections, but it has made the units very safe. In fact the radiation dose received on the skin of the patient is usually half that received from more common X-ray equipment.

Several WHO-specified X-ray units have been thoroughly tested in professional use at university hospitals in Sweden, England and the Netherlands. Others have been equally well tested in small government or mission hospitals in many parts of the world, often operated by staff who have no formal radiographic qualifications. The results have been equally good, and doctors everywhere have been pleased with the images they have been given for

Many hospital administrators and doctors worry about the dangers of radiation. However, provided the room used for X-ray examinations is large enough (minimum 3.5 m x 4.5 m) and the staff stand behind the mandatory protective screen or wall during each exposure, there is negligible radiation risk to the personnel. As already noted above, dosage is low because of an optimized examination technique, resulting in very few retakes. As far as is currently known, ultrasound poses no risk for patient or staff.

WHO has specified complete systems for imaging with X-rays and ultrasound, and can provide expert guidance on the design and layout of X-ray rooms and the requirements for radiation safety. The equipment meeting these specifications is available from various manufacturers.

The WHO imaging system should be made available to all people everywhere, providing optimum help whenever they are ill. ■

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The WHO Imaging System – Radiography (WHIS-RAD)

WHIS-RAD is designed to be used in any X-ray department by fully trained radiographers or by radiographer's assistants under proper supervision. It is intended for radiography of standing, sitting and lying patients. The image quality can be as good as those in a teaching hospital.

Optimum imaging conditions are built into the system, including fixed imaging geometry, using the pendulum principle for angulation of the X-ray beam, and a permanently centred anti-scatter grid.

High-tech X-ray generators are used, using multipulse inverter technology and energy storage in batteries, which results in shortest possible exposure times and very reproducible X-ray tube output. The batteries can be powered from a 230 volt, 10 ampere AC wall outlet or from a solar panel. A single-phase X-ray generator, directly connected to a common 50/60 Hz electric wall outlet, cannot be used.

"I didn't think, I investigated"

This was the answer Röntgen gave when asked what his thoughts were when he discovered X-rays. A thorough researcher and a brilliant experimentalist, he believed that science did not belong only to scientists. Shortly after the "new kind of rays" were first reported, a major German electrotechnical company tried to negotiate a copyright deal with him on all his future discoveries and inventions. Röntgen refused, and thus forfeited the chance of making huge profits. He considered his discoveries belonged to humanity and should not be hampered by patents, licences, or monopoly contracts. He did not even secure the copyright on his first X-ray pictures. He also rejected an offered title that would have made him part of the German nobility, and donated to the University of Würzburg the money he received from the Nobel Prize conferred on him in 1901. His generosity of spirit certainly contributed to the rapid spread of the new discovery and paved the way for the extraordinary developments in imaging techniques that were to follow.

Adapted from: The Health Physics Society Centennial Calendar (1994); and O. Glasser, Wilhelm Conrad Roentgen and the early history of the Roentgen rays, *London, J. Bale, Sons & Danielsson, 1933.*

Mammography: a woman's perspective

Cari Borrás

Breast cancer is particularly dreaded because of the mutilation it causes. In the USA one woman in eight develops it, in the United Kingdom one in twelve. It is also becoming more common in developing countries, as many of the infectious and parasitic diseases gradually come under control. What is to be done about it? At present the best answer is to detect it early so that it can be treated with minimal surgery, which gives the best cosmetic results and the least psychological trauma. If the cancer is discovered in the "preclinical" stage, the probability of cure lasting for at least 20 years is 93%.

At present, the only way to make a reliable early diagnosis of breast cancer is with mammography, a specialized radiographic technique for studying the mammary gland. Because the breast does not contain high density material, such as bones, it is difficult to radiograph. An image produced with the normal technique for a chest X-ray, for example, will show a uniform mass without any detail. Much better results can be obtained with a special X-ray machine using a mammographic technique (see photos).

To detect small lesions, high contrast and resolution are needed. As in photography, they can be obtained with slow film, which requires a longer exposure. This has to be balanced exactly against the need to keep the radiation dose to a minimum. With the right equipment and procedures, a sufficiently clear and detailed mammogram can be produced. Then, equally importantly, it must be interpreted by a qualified specialist.

The fact that the technical means of controlling breast cancer exist raises a number of important questions about how they should be used. For instance, are these means available in all countries? Are the physicians who interpret mammograms adequately trained? How is the quality of the equipment assured? Who makes sure it is being properly used? Are women aware that they should have a periodic breast examination? Do they practise self-examination?

If there is no quality assurance for existing mammography services, perhaps the patients themselves should demand it. Private patients can do this very easily, but what choice do the others have? What should women do to assert their right to survive and to do so with minimal surgery? One strong argument they can use is that a mammography screening programme may be the least expensive screening programme there is, when one compares the cost per mammogram with the number of years of life saved. In terms of action, perhaps women should start by demanding a review of breast cancer incidence in their community and of the health services needed to control it. Such services must include public information and education, as well as diagnosis and treatment. ■

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High tech at low cost

Peter E. Peters & Horst Lenzen

Medical imaging has come a long way from the machine that made the first image of Bertha Röntgen's hand to the highly sophisticated computerized devices available today. Röntgen refused to patent his discoveries and inventions, though invited to do so, on the grounds that such things belonged to humanity, whose use of them should not be restricted. This noble attitude certainly contributed to the rapid development of X-ray technology, although subsequently a large number of patents were filed by others for improvements of his technique. The improvements have been accompanied by rising costs. A hundred years ago, Röntgen complained to his glassblower about the high price and short lifespan of the X-ray tubes he used, but at that time they were about 1000 times cheaper than they are today.

The costs are even higher for the advanced types of medical imaging, in which a number of thin cross-sectional images are taken rather than one single X-ray picture. This technique requires the use of computers, which need a stable power supply and often must be kept in air-conditioned rooms. These needs cannot be met in many parts of the world, and thus millions of people are excluded from these benefits. But things are getting better, and high tech at low cost is no longer a dream.

Mainly because of mass production, computers are becoming cheaper, more powerful, and less sensitive to adverse environmental conditions. Television sets and transistor radios were once rare and expensive but are now found in almost every corner of the world.

Conventional X-ray examination became widely available through the development of rugged, high-quality, low-cost equipment. In a similar fashion, ultrasound imaging devices have been developed which can be used under demanding environmental conditions such as high temperatures, high humidity, and erratic power supply. Even the most sophisticated imaging technique, computerized tomography, is now approaching global distribution. Recent models do not require special power lines or air-conditioning, and can complete a study even when there is a total black-out. Their battery back-up system can be recharged with solar energy collectors when power cuts are prolonged. The latest devices use strong magnetic fields to generate images. The equipment is still extremely expensive both to set up and to maintain, but affordable magnetic resonance imaging machines should be on the market before the turn of the century.

High tech at low cost is therefore possible and, most importantly, low cost does not mean low quality. The current very high prices for modern imaging equipment can easily be cut if minor limitations in speed are accepted. If one considers the time necessary to transport a patient to the nearest major city where one of these devices is available, it may be feasible and more economical to have a somewhat slower imaging device in several district-level hospitals. ■

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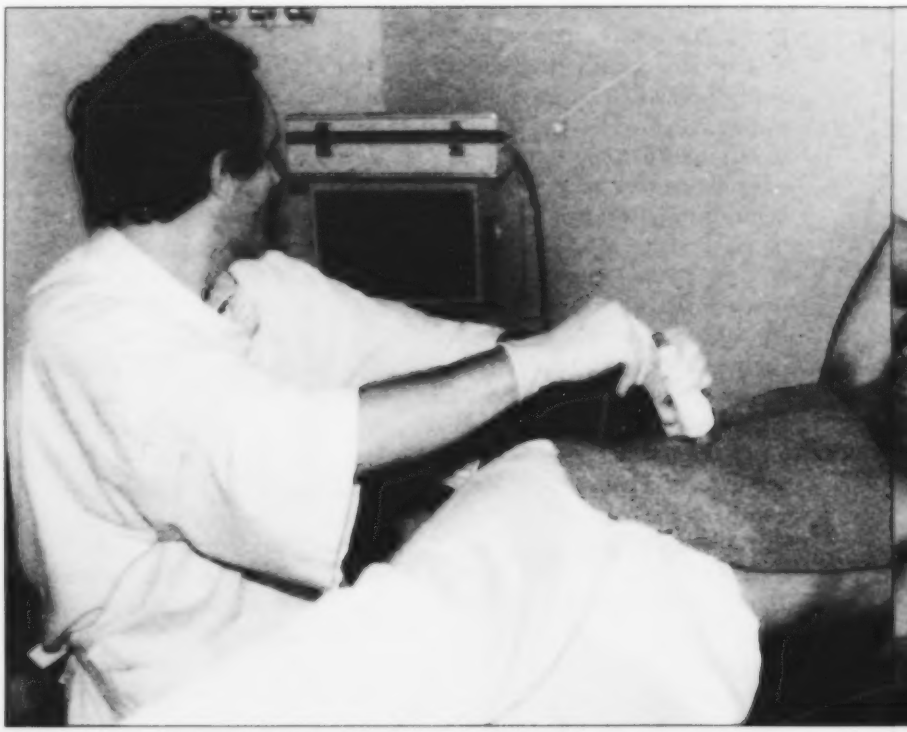
Ultrasound imaging in developin

Hassen A. Gharbi & M.W. Wachira

Despite considerable and growing worldwide investment in diagnostic imaging technology, about two-thirds of the population in developing countries do not have access to even the most basic X-ray or ultrasound diagnostic services.



Draining a liver abscess under ultrasound control in Tunisia.

Since the first attempts in 1954 to use ultrasound waves in medicine, this technique has developed with spectacular rapidity. It is now a well-established and widely recognized diagnostic imaging discipline which enjoys increasing popularity among clinicians. An important reason for its success is that ultrasound equipment is smaller and less expensive than other imaging devices and does not have special requirements for premises and installation. The market for ultrasound imaging is doubling approximately every 5 years and today represents about 20% of the world market in diagnostic imaging. However, as ultrasound cannot scan bones or the lungs, X-rays must remain the first choice for diagnostic imaging equipment in rural and district hospitals.

Clinical uses

Ultrasound is useful for diagnosing a wide range of diseases and pathological changes in the thyroid, liver, gall bladder, pancreas, kidney, blood vessels and other organs and tissues. It can also give precise answers to many of the urgent questions which may arise during pregnancy. The introduction in clinical practice of Doppler and colour Doppler techniques has made it possible to observe fetal cardiac activity and to visualize blood flow within arteries and veins.

In many developing countries, ultrasound may also have an important application in diagnosis and monitoring of parasitic diseases such as amoebiasis, schistosomiasis and Chagas disease. For example, hydatidosis is quite common in Mediterranean, West African and South American countries. The asymptomatic infestation rate varies from 1.8% in Tunisia to 5.6% in Turkana, Kenya. Studies have shown that 95% of cases of hydatidosis in the liver and abdomen were diagnosed by ultrasound. The other 5% were diagnosed with other imaging modalities such as conventional radiology or computerized tomography (CT). Ultrasound has also been helpful in the treatment of hydatid cysts. In 1986 Dr M. Gargouzi, of Tunisia, developed a new technique which he called "PAIR": *puncturing* of the cyst under ultrasound control, *aspiration* of contents, *injection* of a scolicide solution (hypertonic saline or alcohol) and *re-aspiration* of the contents again. At present this technique is used in Croatia, France, Italy, Paraguay, Tunisia, Turkey and Yugoslavia.

Ultrasound was first used for medical investigations and treatment

countries

about 25years ago. Today it has a wide variety of uses. For instance it is used to guide various procedures such as drainage of abscesses, cryogenic surgery on the liver and prostatic cancer, implantation of radioactive seeds for cancer therapy, and fine-needle biopsies from such organs as the liver, pancreas, kidney or lymph nodes.

Since the beginning of the use of ultrasound in medicine, the question of its safety has been a matter of concern among scientists and public health professionals, and has stimulated intensive discussions in the scientific literature. According to the current data, although some evidence suggests the possibility of a risk occasioned by ultrasound examination of the fetus, no human injuries resulting from its use for diagnostic purposes have been reported in more than three decades.

Availability and cost

Despite considerable and growing worldwide investment in diagnostic imaging technology, about two-thirds of the population in developing countries do not have access to even the most basic X-ray or ultrasound diagnostic services. In 1988 there were only about 1000 ultrasound units for the 600 million people in Africa. Today, according to rough estimates, there are about 10 000 – a tenfold increase in five or six years. However, in many developing countries ultrasound is used by a wide spectrum of medical professionals including doctors, nurses, midwives and others who have not had proper training in this imaging technique. This frequently leads to the misuse of ultrasound which, in addition to the potential harm done to the patient because of incorrect diagnosis, increases the cost of health care. At present, therefore, the education and training of medical staff who want to use ultrasound is a key issue in many countries. The nongovernmental professional associations such as the Mediterranean and African Society of Ultrasound (MASU) and the World Federation for Ultrasound in Medicine and Biology (WFUMB) are collaborating with WHO in attempting to improve the standards and training process in this technology. Since its creation in 1986, MASU has organized training courses in Algeria, Burundi, Chad, Egypt, Kenya, Morocco, Syria, Tunisia and Turkey.

The price of an ultrasound machine can vary from US$ 10 000 for a simple general purpose scanner to US$ 300 000 for specialized equipment. Fortunately, a simple unit is suitable for 70-80% of the ultrasound examinations for diagnosis of the most common clinical problems. A WHO group of experts has drawn up technical specifications for this kind of machine, which is portable and well adapted to conditions in developing countries. It appears that such units are at present produced by several commercial companies.

In conclusion, it would not be an exaggeration to say that ultrasound has revolutionized medical practice in terms of providing easier access and increased quality of diagnostic service for patients. However, much work is still needed to make this useful technology accessible to all who could benefit from it. ■

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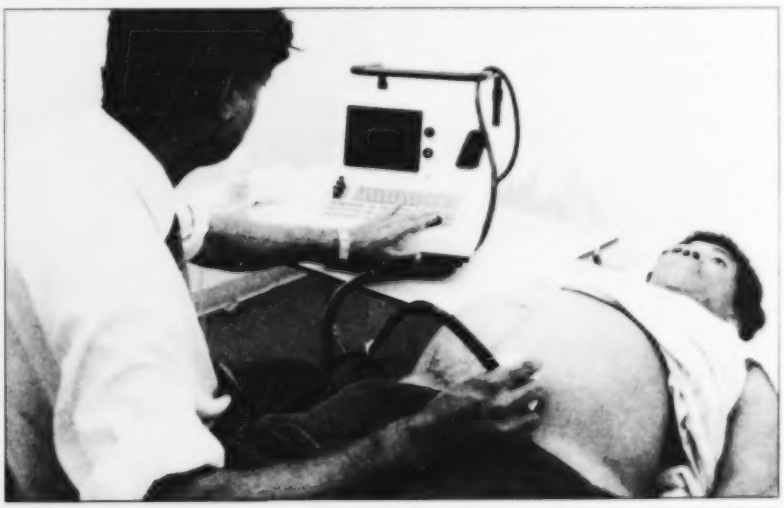


A prenatal check on the baby's health in Mauritius.

Nuclear medicine

Yasuhito Sasaki & Kiyoko Kusakabe

Data from the scintillation camera can be interpreted by computer to permit a refined diagnosis.

Nuclear medicine is constantly expanding through the introduction of new radiopharmaceuticals and new instruments. Special radiotracers, for instance, are making it possible to study fatty acid metabolism in the heart muscle.

Nuclear medicine is the application of tracer technology to medicine. Chemical compounds labelled with a radioisotope, which are called radiopharmaceuticals, are either administered to patients (*in vivo* studies) or labelled compounds are mixed with other reagents in test-tubes to measure minute quantities of hormones, certain drugs, and other substances. The amount of radiopharmaceuticals and labelled reagents is so small that it does not interfere with the natural behaviour of the target substance in the body or with biochemical or immunological reactions in test tubes.

After an intravenous injection of such a compound, the patient just lies on the bed while a scintillation detector called a gamma camera measures the radioactivity to record multiple images of the organ concerned from different angles. These images are then interpreted by a computer and the tomographic images serve to detect the location of any abnormality. Such *in vivo* procedures can detect a diseased organ by measuring the localized physiological and metabolic function in a tissue, organ or lesion which can be displayed as a functional image. The radioisotopes used have a half-life as short as six hours, with very little radiation exposure for patients.

How it began

Shortly after Röntgen's discovery of X-rays, the experiments of Henri Becquerel led to the discovery of what was later named "radioactivity" by Marie Curie. Further studies by Marie and Pierre Curie, Ernest Rutherford and Frederick Soddy opened the door to the medical applications of radioisotopes emitting β- and γ-rays.

George von Hevesy was the first to use radioisotopes to trace the behaviour of a substance in plants and animals by monitoring the radioactivity. This tracer principle was first applied to human beings by Hermann Blumgart and Soma Weiss in the late 1920s to measure the speed of the bloodstream. They

injected a radioisotope into a vein of the arm and measured the time it took for radioactivity to reach the other arm.

The discovery of artificial radioisotopes in 1934 by Irène Curie and her husband Frédéric Joliot gave a boost to the application of the tracer principle. The medical application of substances labelled with radioisotopes was accelerated after radioisotopes were made available to the private sector in 1946 in the USA. Measurement of insulin levels in human blood was first reported in 1959 by Solomon Berson and Rosalyn Yalow. This new technique was named radioimmunoassay (RIA) and opened up a new horizon for the diagnosis of hormonal disorders.

Frequent diagnostic tests

In Japan, about 6600 *in vivo* studies are performed every day in some 900 nuclear medicine facilities in hospitals. The most frequently performed diagnostic tests are bone scintigraphy using labelled phosphate compounds – the most sensitive test for detecting bone metastasis – followed by tumour scintigraphy, myocardial scintigraphy and brain perfusion scintigraphy.

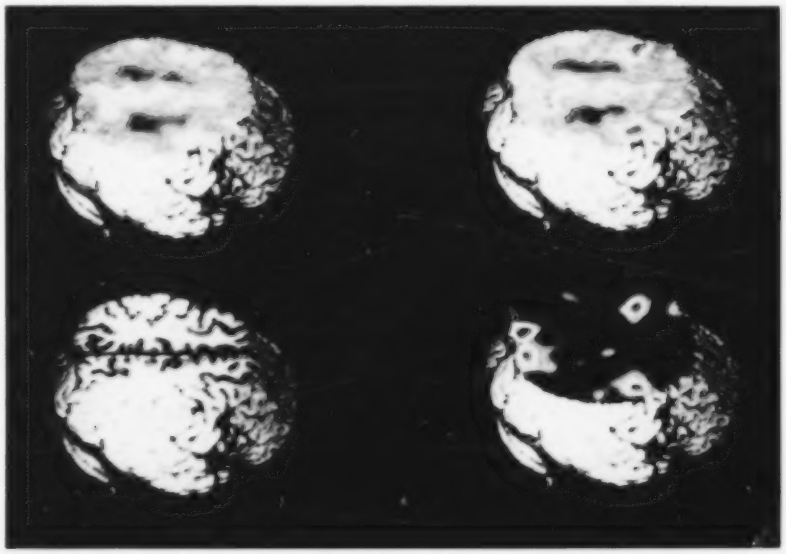
Radiopharmaceuticals are also used for therapy. In 1992, for example, 2000 Japanese patients with hyperthyroidism and 1000 thyroid cancer patients with metastasis were treated. Therapeutic use of unsealed radioisotopes has been playing an increasingly important role since the introduction of monoclonal antibodies labelled with beta-ray-emitting radioisotopes, which bind to tumour-related antigens produced by the cancer and irradiate the cancer tissues locally. Similar substances have been used for the effective control of intractable bone pain caused by bone metastasis.

Nuclear medicine is constantly expanding through the introduction of new radiopharmaceuticals and new instruments. In cardiac nuclear medicine, for example, new myocardial perfusion agents labelled with special radioisotopes have been available for the past few years, making it possible to study fatty acid metabolism in the heart muscle. Labelled monoclonal antibodies have been attracting great interest and are the subject of vigorous research for use in both diagnosis and therapy.

An imaging instrument called positron emission tomography (PET), in combination with a small in-house cyclotron, can produce radioisotopes which decay very rapidly with half-lives as short as two hours. This has excited clinical research workers in nuclear medicine since with PET we can evaluate regional tissue metabolism, which reveals tissue consumption of oxygen, glucose, amino acid and fatty acid. Moreover PET can visualize activated nerve cells, which will make it possible to study higher brain function such as speech, cognition, thinking and emotion. The use of nuciear medicine to help us to understand human behaviour will thus play an important role in evaluating psychiatric patients, including those with dementia.

It will also be possible to measure the sensitivity to drug action of individual patients by visualizing the sites of drug action. The therapeutic drug regimen can then be precisely tailored to suit the individual's need.

Nuclear medicine is the result of collaborative efforts in physics, chemistry, computer science, physiology, clinical medicine and, recently, immunology. Its applications, in some instances, may need support by a national health care system because of the high cost. The development of relatively inexpensive devices and radiopharmaceuticals is therefore important if nuclear medicine services are to be available to all who need them, including patients in the developing countries. ■



Nuclear images of the brain. Positron emission tomography and magnetic resonance are helping doctors to understand some of the mysteries of the brain's functions.

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Radiotherapy: still young after almost a hundred years

Jean-Claude Horiot & Suzanne Naudy

-rays were first used to treat a cancer patient in December 1895, only four weeks after their discovery by Röntgen. A few months later, in March 1896, Henri Becquerel discovered radioactivity. Less than two years after that, Marie and Pierre Curie announced the existence of two radioactive substances: polonium and radium. The beneficial consequences of these three amazing years of discovery are still unfolding now, a century later. Radiotherapy, alone or in association with other methods such as surgery and chemotherapy, has become one of the main weapons in cancer treatment, and often the one which most effectively cures while causing minimal disturbance to the anatomical structures and functions concerned.

Past achievements and future expectations are based on three disciplines.

- *Clinical medicine* and a century's experience in the use of (*a*) external radiotherapy, nowadays increasingly by means of photon and electron linear accelerators; and (*b*) brachytherapy (curietherapy), which is internal radiotherapy by means of radioactive sources placed in tissues or natural cavities for periods ranging from a few minutes to a few days.
- *Radiophysics*, which makes it possible to measure the exact amount of radiation delivered to the patient (the dose) and to distribute it effectively so as to destroy cancerous tissue whilst preserving healthy tissue.
- *Radiobiology*, which continues to improve our understanding of how radiation works and makes a major contribution to the effectiveness with which it is used on both normal and diseased tissues.

Modern radiotherapy has three main concerns: efficacy, quality of life, and safety. With regard to efficacy and quality of life, which are often hard to separate, radiotherapy selectively destroys the cells responsible for setbacks after surgery in more than 90% of the cases in which it is used. In treatment for breast cancer, for example, this treatment is often so effective that it is impossible to see that the breast has been treated.

There are two methods of particular note which make it possible to select the area for irradiation with greater precision than before.

(1) Brachytherapy with iridium 192, which is the most commonly used radionuclide today. A piece of iridium wire, a few tenths of a millimetre in diameter, can be inserted, usually under local anaesthetic, in various parts of the body such as the cervix and uterus, breast, ear, nose, throat, oesophagus and bronchi. It delivers a very high and very localized dose which leaves adjacent tissues unaffected.

(2) Conformation radiotherapy, which is guided by three-dimensional dosimetric modelling using the modern imaging techniques of computed tomography and magnetic resonance imaging. Prior to treatment, a computer-generated virtual patient is used to determine the configuration closest to the ideal prescription for the maximum dose to the tumour and the minimum dose to the healthy structures and organs at risk. This method has raised great hopes, as it should make it possible

to increase the dose according to need. For many cancers, an increase of 15% in the dose leads to an increase of similar proportions in the rate of cure. Thus, for certain localized cancers, a success rate of over 90% has already been reached or can be expected in the coming years.

Finally, safety: the practice of quality assurance, common enough in industry but still all too rare in medicine, has developed rapidly in radiotherapy since 1980 because everything can be measured and recorded. Quality assurance techniques are now used to check the amount of the dose, the reliability of the installations, the validity of the treatment plan and even the possibility of using the same treatment in a subsequent session or a different hospital. Today it is a fundamental part of both international clinical research and the safety of radiotherapy in daily practice.

Unfortunately, radiotherapy is not accessible to everyone on the planet. The industrialized countries have 90% of the equipment and the skilled personnel needed to use it. This situation should be viewed not as a discouragement, but as a stimulus to further progress: investment in this field is almost bound to be extremely beneficial, in terms both of economics and of human well-being. ■

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An orthographic puzzle

This year marks the centenary of Röntgen's great discovery. Ironically, the discovery launched one of the more controversial four-letter words in the English language. The word "X-ray" is used as a noun with two distinct meanings (the radiation itself and also the processed image), as an adjective (as in X-ray equipment) and as a transitive verb (to X-ray an object or a patient).

But should it be written with a capital X or not, and should it have a hyphen or not? Guidance and precedent may influence the use of English, but never immutable rules! Originally, the word may have started as a "proper name" written with a capital "X". But today it is only one of many forms of electromagnetic radiation, which includes light, heat and ultra-violet radiation. So some experts use "x-ray" while others stick to "X-ray". Röntgen's original paper of 1895 refers to "X-Strahlen", since in German all nouns start with a capital. But should that influence modern English writing?

The Shorter Oxford Dictionary even includes the possibility of replacing the hyphen with a space (x ray). The implication that "X" (or "x") can have a meaning by itself, is hardly a tenable proposition. "X" is not a word but simply a prefix that gives a special meaning to "ray" (compare alpha-ray, gamma-ray, etc.). As a connector of the qualifying prefix to its body, the hyphen seems to be mandatory. Then the question arises whether to use a capital "r" – X-Ray.

In the end, the only consensus view is that the spelling should be consistent throughout any given publication!

Contributed by Colin W. Robertson, formerly in charge of the radiological section of the Medical Devices Directorate of the U.K. Department of Health, and a member of expert committees of the International Electrotechnical Commission (IEC). His address is 7A Talbots Drive, Maidenhead, Berks SL6 4LZ, England.

Quality assurance in radiotherapy

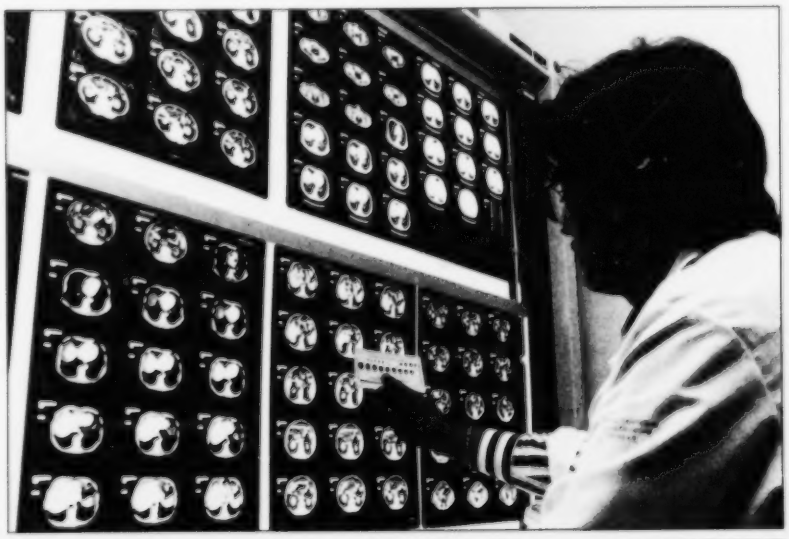
Hans Svensson & Björn Zackrisson

According to WHO's estimates, about 9 million new cancer cases occur each year worldwide. This number is expected to increase to about 15 million by the year 2015, with about two-thirds of these in the developing countries. A recent European Union document states that radiotherapy is no longer the key research topic but is the most widely used treatment for cancer. In the developed countries it is involved in almost half of the administered cancer treatment, either on its own or in combination with surgery and/or chemotherapy. In the future, radiotherapy will undoubtedly play an increasingly important role in most countries.

Exact diagnosis and tumour size

The decision to use radiotherapy must be based on careful determination of the histological type and extent of the tumour. Traditionally, X-ray pictures delineated the tumour's position and volume in the patient. A simple cross-section on a scale of 1:1, based on the contour of the patient, was constructed to show the suspected volume of the tumour for radiotherapy and also to indicate the healthy tissues that should have a low dose. The uncertainty in the delineation of the tumour was often large, and the radiotherapist had to increase the radiation field in order not to miss parts of the tumour. The prescribed dose had to be reduced when large volumes were irradiated, and this decreased the chance of eradicating the tumour. In spite of these problems many patients were cured.

The introduction of computerized tomography (CT) has improved the possibility of delineating some tumours accurately. When this method was first introduced the tumour's position was often determined by using both conventional X-ray equipment and CT-scanners. In several centres it was discovered that the conventional method missed part of the tumour in up to 40% of the cases examined. Much research is being devoted to improving the accuracy with which the tumour's position in the body can be determined.



Reviewing computed tomography images. CT-scanners delineate tumours very accurately.

Dose planning

For curative radiotherapy an accurate dose plan is required. In many advanced radiotherapy centres, dose planning was still being done without a computer at the beginning of the 1980s. Today even small departments can often afford a treatment planning system, as it can be run on an ordinary personal computer. Computer-based dose planning generally increases the accuracy of dose determination, but it can also cause errors, especially in the hands of untrained persons. Input data, determined by the medical physicist, must be available from the local radiotherapy machines. The incorrect use of dose planning systems has been known to lead to large errors; for example in one centre doses that were 20-30% too low were given to several hundred patients. The dose planning system should therefore be handled by a competent medical physicist and a quality assurance programme is essential.

Dose measurement

Modern radiotherapy is based on the experience of a large number of radiotherapy departments all over the world. The amount of radiation that is required to control a certain type of cancer without causing serious complications is a matter of continuous discussion in scientific journals. The difference between a dose level

which achieves local control of the cancer and one which causes serious or fatal complications is sometimes very small. The radiation oncologist must therefore make sure that his department can measure the dose so that it complies with the international standard, and determine the dose to the tumour and organs at risk with a high degree of accuracy (generally to within 5% of what is prescribed).

Several international organizations are involved in the standardization of dose measurements. The International Bureau of Weights and Measurements in Paris has established an international reference standard, and IAEA and WHO have jointly promoted the establishment of a system known as the secondary standards dosimetry laboratory (SSDL) network, which now covers most of the world. IAEA is responsible for checking the quality of the calibration services used by the individual laboratories in the network. To check individual centres, IAEA and WHO have organized services for hospitals; 1000 radiotherapy centres have now been checked and about half of them are able to calibrate the treatment beams to within 5%.

Irradiation of the patient

The radiation field arrangement planned for the patient is checked with a special X-ray diagnostic unit which serves as a simulator. The beam directions and field sizes are set up as for treatment with the therapy machine. If there is a risk of the patient moving during treatment for which the precision of the field settings is critical, fixation should be used for both the simulation and the therapy irradiation.

The first treatment of the patient at the therapy machine is crucial as the same parameters are used in subsequent treatments, of which there are usually 30 or 40. The whole team responsible for this procedure – i.e. the radiation oncologist, the medical physicist and the radiographer – should participate in it (see Figure, below left). Dosimeters for *in vivo* measurements are recommended for checking the correct dose to the patient (see Figure, below right).

Future

In advanced countries today there is one high-energy therapy unit (accelerator or Cobalt-60) for every 500 to 1000 new cancer cases occurring in a given year, about half of which are treated with radiation. It would therefore require at least 10 000 radiation machines for external radiotherapy plus a large number of radiation sources for brachytherapy in developing countries by the year 2015 if the need is to be met. There is concern about the spread of radioactive material to a large number of hospitals. For instance, what happens when these sources are no longer in use? International agencies such as WHO and IAEA can greatly help in organizing activities such as setting up SSDLs, but the direct responsibility must be shouldered by the countries themselves. Adequate staff, with qualified radiation oncologists and medical physicists, as well as equipment for dose measurements and a programme for quality assurance are needed. Certainly, with adequate infrastructure and skill, radiotherapy will cure or give palliative relief to a large percentage of the world's cancer patients without undue risk. ■

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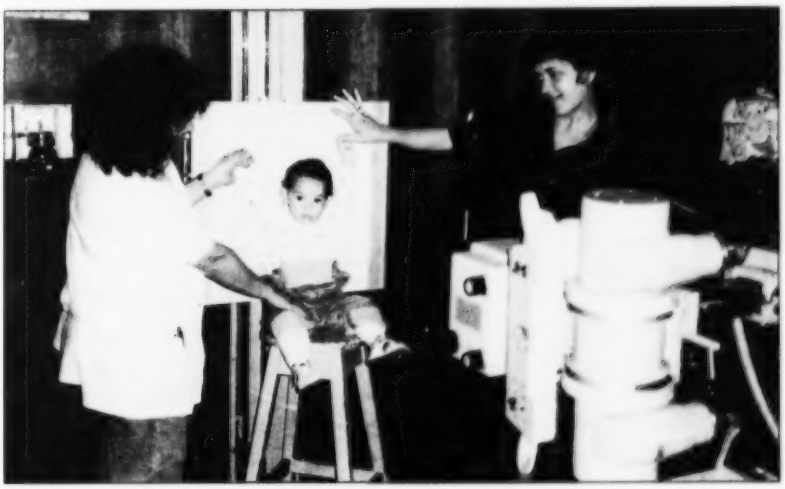
A radiographer, a radiation oncologist and a medical physicist plan the dose of radiation to be given to a patient.

Dosimeters applied to the skin allow radiation oncologists to monitor the optimal irradiation dose.

Protection against radiation in medicine

César F. Arias & Jorge J. Skvarca



Radiology in paediatrics calls for special protection procedures for the young patients.

The protection of patients is the area in which the greatest reductions in human exposure to radiation can be made – by improving the quality of equipment and practices and raising the standard of justification for procedures.

The discovery of X-rays by Röntgen in 1895 and radioactivity by Becquerel in 1896 opened up the field for using ionizing radiation in science and technology. This proved to be a valuable tool for research on the structure of matter, and its applications in medicine have been explored since the beginning of the century. Ionizing radiation is now used for medical purposes in three areas: diagnostic radiology, radiotherapy, and nuclear medicine. Throughout the world, there are about 800 000 X-ray units being used for diagnostic radiology; 4000 cobalt radioactive sources and 1800 accelerators being used for radiotherapy; and 13 000 nuclear medicine clinics using unsealed radioactive sources for diagnosis and therapy.

The growing complexity of radiation medicine can be seen in the use of such devices as computerized tomography in diagnostic radiology, linear accelerators in radiotherapy, and positron emission tomography in nuclear medicine. This has led to the need for maintenance and quality control of equipment, using highly specialized personnel.

The risk of radiation

Human beings are naturally exposed to the radioactive substances of the earth, and to cosmic radiation. Globally, the average dose per person is about 2 millisieverts (mSv) per year, which is about 10 times the dose received from a simple X-ray examination.

When X-rays and radioactivity first came into use, little was known about the effects of ionizing radiation on health. It was the acute effects, such as skin erythema, cataracts and reduced production of blood cells that were recognized first. These only occur when tissues receive doses of radiation several thousand times as large as those received by an average person in a year from natural radiation. The carcinogenic effects were discovered later, and some information on them was gathered from studies on patients who had been treated with radiation and workers painting radium on the dials of watches. After the bombing of Hiroshima and Nagasaki, large-scale epidemiological studies showed that the probability of cancer grows with the dose of radiation absorbed.

Whenever radiation is used for any purpose, people working with it, as well as some members of the public, are *unavoidably* exposed to small doses of radiation under normal circumstances. In the case of medical use, the patient is *deliberately* exposed to radiation in order to obtain the necessary diagnostic information or for treatment. In addition, accidents can occur in which people receive high doses.

Protection against radiation

The Second International Congress of Radiology, held in Paris in 1928, recommended the establishment of an international organization to study the question of protection against radiation. This was the origin of the International Commission on Radiological Protection (ICRP). The ICRP has produced about 70 publications and its recommendations have been followed by most countries, as well as by various international organizations such as WHO and the International Atomic Energy Agency (IAEA).

A radiation protection specialist checks equipment to ensure that it meets safety requirements.

In 1990 the Commission published *ICRP Publication 60*, which provided an update on radiobiology and the current conceptual framework for radiation protection. The following points from this publication give an indication of its basic philosophy.

- Every exposure to radiation may have detrimental effects on human health, since the carcinogenic effect of radiation cannot be completely avoided.
- No practice involving exposures to radiation should be adopted unless it produces sufficient benefit to the exposed individuals or to society to offset the radiation detriment it causes.
- Dose limits, defined as a level of dose above which the consequences for the individual would be widely regarded as unacceptable, are set as follows: occupational exposure should not exceed 20 mSv per year and no member of the public should receive more than 1 mSv per year. The risk of accidents must be considered.
- All exposure should be kept as low as reasonably achievable. Protection against radiation is a matter of professional culture, and national regulatory authorities work to promote appropriate attitudes as well as compliance with the rules. To provide them with the necessary information for doing this, the ***International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources*** were prepared jointly by FAO, IAEA, ILO, the Nuclear Energy Agency (NEA) of OECD, the Pan American Health Organization (PAHO) and WHO. WHO also works with countries to improve standards through training and consultation on the procurement and use of equipment.

Medical establishments are the most numerous and widespread source of radiation in any country, and because their activities are mainly beneficial, the risks involved are often ignored. This makes the promotion of proper protection a difficult task. In the case of a patient's exposure, the risks and the benefits apply to the same person, and must be carefully weighed against each other by the physician responsible. Dosage must be limited to what is strictly necessary; limits have not been set because they depend on the possible benefits, but reference levels are being suggested for use in radiology and nuclear medicine as a means of judging the quality of equipment and procedures.

A radiographer views the patient from inside her protected control booth.

The protection of patients is now receiving particular attention, as it is the area in which the greatest reductions in human exposure to radiation can be made. The global collective dose received by patients from diagnostic radiology is 5000 times greater than the dose received by the world's population from nuclear power production. A significant part of that dose could be avoided without loss of health benefits by improving the quality of equipment and practices and raising the standard of justification for procedures. To prevent accidents where radiation is used for medical purposes, safety measures have to be adopted in the design, installation, use, repair and eventual disposal of equipment. ■

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Radiation expert

In the same year that radioactivity was discovered – 1896 – one of the leading scientists in medical radiation physics and radiation protection, Rolf Maximilian Sievert, was born in Sweden. He entered the medical physics field in 1920 and is known for his theoretical calculations of the dose distribution around radium tubes (Sievert integral), for the design of dosemeters (Sievert chambers), and for his research in radiation protection.

Sievert was for many years chairman of the International Commission on Radiological Protection (ICRP), and the initiator and chairman of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). He retired in 1965 and was honoured after his death by having the unit for "dose equivalent" named after him as the Sievert (Sv).

Radiology in the *next* hundred years

Alexander R. Margulis

Coronary angiography examination. A radiation-opaque dye injected into the body outlines arteries and shows up any obstruction on the screen.

If we review the accomplishments of imaging during the last 100 years since Röntgen's discovery of X-rays, we must conclude that progress was initially slow but gained speed, with momentous advances in technology. The relatively early breakthroughs were the image intensifier and television viewing, which made interventional radiology possible and transformed gastrointestinal fluoroscopy into an objective, detailed, data-gathering discipline. Radiology benefited from the spin-off of space exploration and Cold War defence technology, resulting in breakthroughs in computers, electronics, the move from tubes to transistors to printed circuits on boards to silicone chips, miniaturization, telecommunications and fine-detail television screens.

As a result of these technological advances, new imaging disciplines appeared in the 1970s. Ultrasound made it possible to study the blood flow, while fetal ultrasound is discovering congenital disorders *in utero* and makes early therapy possible. Intra-operative ultrasonography is capable of finding disease within organs such as the liver and guiding the surgeon during an operation. Computerized tomography (CT) has moved towards greater speed of scanning and more detailed imaging.

To be able to prosper in the future, medical imaging must continue to decrease in invasiveness, increase in sensitivity and specificity and – more than anything else – remain affordable and patient-friendly.

Magnetic resonance imaging has brought about fast, highly informative imaging and has become a competitor to CT in everyday cross-sectional high-detail imaging and problem-solving. Magnetic resonance spectroscopy is becoming a clinical problem-solving modality for brain tumours, while interventional radiology is making advances with the introduction of catheters through the femoral artery to carry radiotherapy to an affected organ. Indeed interventional radiology, which in the beginning used only fluoroscopy with television viewing for imaging control, is today also employing ultrasound, CT and now magnetic resonance imaging.

Threat to progress

The explosive progress in imaging, however, has also coincided with the general rise in the cost of medicine, producing a reaction which is threatening further progress. With large expenditures for health everywhere and the glaring visibility of expensive imaging instruments, the general feeling is that high-technology imaging should be stopped and that the spread of expensive cross-sectional imaging equipment should be heavily controlled. Government support for imaging research is slowing and, as industry finds this less profitable, it cannot support bold, new, adventurous approaches. It is, therefore, highly unlikely that new cross-sectional imaging techniques will be

developed in the near future.

Biomagnetism may be an exception and is most likely to become a clinical new imaging modality. It is important in brain surgery to avoid damaging critical motor and sensory centres, and its application in the heart is in detecting arrhythmias, a frequent cause of unexpected sudden death. Infrared laser CT shows some prospects of feasibility but needs government or industrial funding, which is at present in short supply. With this bleak and pessimistic outlook, what is the future?

Existing cross-sectional equipment will become less expensive, and there will be a spectrum from low and very affordable to intermediate and then to highly sophisticated equipment. The integration of various imaging modalities through computer programs will become an everyday clinical reality, with better display, increased sensitivity and improved specificity. However, with the mushrooming of information, there is the danger of being overwhelmed by it, and it will be necessary to develop picture-archiving communication systems, a needed tool that will link physicians and departments in the same institution and will also communicate with other centres throughout the world that use computers. All radiography will have to become digital in order to be properly archived and retrieved. Images will be randomly retrieved in an instant and could be transferred anywhere. Teleradiology will make it possible to obtain second readings and consultations almost instantly.

Radiology will eventually become filmless as everything is read from the computer screen. This will make radiology more time- and cost-effective. There is probably going to be a separation, at least in practice, between diagnostic and interventional radiology. The latter will become increasingly more fused with surgery. Ultrasonography will become more and more the stethoscope of the future. CT will continue to increase in speed, and magnetic resonance imaging will continue to be a problem-solving modality, particularly in the abdomen.

As imaging must closely follow the mainstream of medicine, all of these modalities will have to be integrated and further developed to serve genetic medicine. With human genome identification of disease gene carriers and gene suppressors, new screening tests will have to be developed. The situation is not simple, as there are diseases that will happen almost inevitably because of genetic predisposition, but most disease-related genes only increase susceptibility, and the actual triggering of disease may involve many factors.

Substitution gene therapy is still in its infancy and is not without risk, while general amniotic genome testing of the fetus still lies in the future.

To be able to prosper in the future, medical imaging must continue to decrease in invasiveness, increase in sensitivity and specificity and – more than anything else – remain affordable and patient-friendly. ■

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The ethics of new technology

Sneh Bhargava

Human embryo. The possibility of examining the unborn baby raises acute ethical questions for health professionals.

In this "space-age" of sophisticated gadgetry, patients prefer to have their illness attended to by the new technologies, which have a reassuring ring to them. But who gets these services – the needy or the rich?

Advances in radiology and imaging science have brought into being a new medical speciality concerned with the unborn fetus. This has raised important ethical questions for health professionals such as: do you abort a fetus with Down's syndrome, hydrocephalus, meningocele, congenital heart disease, or bilateral renal disorders? Or do you institute pre-natal intervention? Or do you permit these defective fetuses to be born?

Further ethical issues arise. Who makes these decisions: doctors, parents or both? Does the newborn child or the unborn fetus have the fundamental right to be born with a sound mind and body? Technological advances have also provided a means of sex selection and, in some cultures, parents may be inclined to destroy unwanted female fetuses. Even some obstetricians and radiologists consider that sex selection and selective abortion of the unwanted sex can be morally justified, arguing in favour of "population control" or the heavy social responsibility of bringing up female children in certain developing countries where girls – especially impoverished girls – face a lifetime of discrimination and even worse.

A quite different problem arises as a result of the progress and evolution of high technology in health care and its escalating costs. This concerns the ethical and moral issues of availability, accessibility and affordability of the services that radiology can offer. Are they a right or are they a privilege? Whose responsibility is it to ensure that the needs of the many are not ignored while the privileged few are favoured?

Such questions form part of the broader problems that health care professionals and the community in general have to resolve, namely to balance – on the one hand – self-care, equity, social justice, human well-being and obligations to the vulnerable against – on the other hand – rising costs, cost-benefit, resource allocation and the inclusion or exclusion of specific population groups. Have physicians, economists, epidemiologists, social scientists, policy-makers and the community put these on today's or tomorrow's agenda?

The doctor reassures a patient who is about to undergo a scanner examination. Is access to sophisticated and costly technology like this a right or a privilege?

From X-rays to scans

There is no doubt that the radiological and imaging sciences have made unprecedented progress from simple X-ray films to the era of anatomical scans, whether they be computerized tomographic scans, ultrasound scans, scintiscans, or magnetic resonance scans, whether made with ionizing or non-ionizing sources. Such scans have not only laid bare the human anatomy with millimetre precision but have now embarked on unravelling the brain physiology and body biochemistry at the molecular level, non-invasively. They have brought such precision and confidence to medical diagnosis as never before and are actively involved in every field of medicine from the unborn fetus to the brain dead. So much for the positive side.

On the negative side, they have changed medicine from being an art with a human face to that of a complex science with a dollar value. Their rising costs have increased the gap between the haves and the have-nots in terms of the availability of quality health care. The most vulnerable, the poor and those who are most in need of health care are getting less and less. The new technologies have usurped limited resources, away from preventive health care and primary health care – in part because of the powerful lobbies that industry has created among the medical administrators.

A single scanner may cost US$ 500 000 and the operating costs can only be recouped by using the machines and the services they provide to the maximum. Less expensive services may be and are being bypassed in order to increase the use of these costly therapies and diagnostic aids. There is definitely a psychological aspect associated with complex technology. Patients would rather have their illness attended to by the newer technologies, which have a reassuring ring to them in this "space age" of sophisticated gadgetry. But the ethical question for the medical bureaucracy is: who gets these services, the needy or the rich?

The producers of medical equipment have done a superlative job in persuading health care providers of the merits of their engineered and expensive merchandise. They also provide the wherewithal of financing strategies that make the debt burden easy, even if this results in overuse to recoup operational costs. Inevitably this high-tech equipment is installed only in the capitals and big cities, to the detriment of rural areas already lacking access to health care services. Yet how else can the costs be recovered?

In this connection, the story of cancer is a classic example of the need for partnership in ethics between health professionals, the community and industry. In the mid-1960s there was a great deal of optimism about curative cancer research; by the mid-1970s that research did not fulfil the expectations of the profession and the community. The cancer control movement shifted away from imminent cure towards prevention strategies and efforts to protect people from harmful environments. Increasingly now scientists consider cancer to be 70-90% environmentally and lifestyle induced. For example, about 80% of cancers in US males are attributable to tobacco smoking alone, and 90% of oral cancers in developing countries are due to tobacco chewing. One-third of all cancers are related to tobacco use, which is theoretically under our control but very heavily industry-pushed.

The message should be clear to all. The most insidious agent for disease today is ourselves, the only truly effective treatment is awareness and prevention, and the only valid prevention is to make positive changes in lifestyles. This is an ethical responsibility for the entire community. To make one's own health someone else's duty is unfair to the society of which we all form a part. Doctors must practise not only the science of health care but also the art of compassion, taking into account availability, accessibility and affordability. The medical care system with all its sophisticated gadgetry has, in the end, less impact on health than individual behaviour, lifestyle and environmental factors. ■

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Multidisciplinary research for health

Boutros G. Mansourian & Bruce McA. Sayers

The discovery of X-rays is a fine example of the contribution made by the physical sciences, together with the biological sciences, to the progress of medicine in the last 100 years. More recent advances in diagnostic technologies are the result of important multidisciplinary research in medicine and the natural sciences. For example, the biotechnology industry has grown as a result of the use of the hybridoma technique for producing monoclonal antibodies; recombinant DNA methods are thus available for prenatal screening and, where necessary, for postnatal examination for inborn errors of metabolism. Also, the fact that particular types of tumour generate specific proteins offers opportunities for the development of specific assay techniques for the early detection of cancer.

Improving diagnosis and evaluation

Developments in the physical sciences and technology have produced three major kinds of diagnostic procedures: the wide range of simple, commercially produced disposable kits for the testing of body fluids in the field; electronic diagnostic equipment which was facilitated by microchip technology and, in some cases, is dependent on biosensors; and technology for imaging and visualization.

Disposable "self-test" kits are now commonly used for the approximate estimation of blood glucose, for pregnancy tests and for testing of urine. However, when more precise determination of concentrations is needed, biosensor technology will become important. Biosensors represent the combination of two technologies: microelectronics and enzyme catalysis. Other detection techniques depend on antibody-binding reactions rather than enzyme catalysis, and these offer the possibility of assaying an increasing range of drugs and hormones.

Current and future developments in biosensor technology will be important for monitoring water and air pollution, for monitoring bioprocessing in the food industry, for quality evaluation of food products kept in storage, and for veterinary purposes. Applications in primary health care would also become evident, because such devices are inexpensive and easy to use.

Electronic diagnostic equipment is developing rapidly because microchip technology has made it possible for the individual instrument to be attached to a personal computer or for a microcomputer to be included within it. Advances in diagnostic procedures, such as electro- and magneto-cardiography, electro- and magneto-encephalography, ophthalmography and the Doppler investigation of regional blood flow, depend on quite sophisticated processing which is transparent to the user. Consequently it will be increasingly feasible to perform dynamic measurements, in "spatio-temporal terms", i.e., displaying "surface maps" of the physiological variable as a series of "snapshots" in "real time", at a hundred times or more per second.

Imaging technologies such as ultrasonography, computerized tomography, magnetic resonance imaging, and positron emission tomography have grown out of basic research in physics, mathematics and electrical engineering. In addition to expected improvements in speed and resolution (e.g., by 1000 times in the still experimental "ion computer tomography"), new efforts are being directed towards extracting information about function for a better evaluation of planned treatments. Of particular interest is the use of ultrasound imaging, achieved by echo-reflection and Doppler effect, which allows conventional visualization as well as measurements of flow and

tissue movement. Special techniques – e.g., colour display of flow mapping which helps visual interpretation, and pulsed Doppler which measures both range and velocity, thus allowing velocity profiles to be examined – are adding complexity, but are also likely to expand the range of investigations.

Relevance to health care

There are two respects in which multidisciplinary research is a potent source of support for health care.

■ Within the particular field of medical radiology, for example, both materials technology and computer technology have much to offer. Thus, the impending development of higher temperature superconducting materials will simplify and render cheaper the costly magnets used in magnetic resonance imagers. At the level of manufacture, high-strength light-weight composite materials could help to reduce the weight and bulk of complex equipment, making their transport in the field easier. Computer technology, coupled with the technology of digital signal processing, is progressively improving the methods for interpretation of medical images, both through technical developments in image enhancement and by incorporating and using semantic information that encapsulates the experience of expert observers. Another imaging technique has also recently evolved from research in combination of materials, computing and signal processing; this ultrasonic examination technique evaluates the state of the walls of arteries and promises improved early recognition of developing atheromas.

■ The overall effectiveness of any specific medical technology depends on where it is needed and on how and through what system structure it is to be operated, so that strategic planning for the introduction and use of this technology is important. Planning the best use of technology within an overall national or regional health care plan requires the consideration of very many factors. Since human planners cannot easily take account of the numerous relevant data that bear upon choices, there is a need for special computer-based tools to help acquire and analyse the essential information, decide on resource allocations, and design organizational structures for the best use of this technology, with plans on how to introduce them. Furthermore, training of personnel may have to be planned and implemented and job descriptions devised. Monitoring of performance may have to be arranged with a view to identifying the need for further training or correcting mismatches between job descriptions and the actual requirements.

Much of this effort has to be based on the insight and experience of experts, planners and consultants who know the country, its systems and its culture well. As their experience and knowledge are often encapsulated in statements, both "knowledge engineering" and the techniques of computational logic are needed to make use of this resource. Potentially valuable developments are taking place in information technology, in the acquisition and use of "knowledge" as distinct from "data" in interpreting national health needs and constraints, in decision support technology, and in the design of project management techniques. Such multidisciplinary research advances should not be overlooked by health planners: not least in developing countries where limited resources have to be stretched as far as possible. ■

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In the next issue

What induces people to abuse psychoactive substances, i.e. substances affecting the mental process and leading to dependence? What are the implications for health? The July-August 1995 issue will give some answers to these important questions and describe possible solutions. ■

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